SOME PHOTOMETRICAL MEASUREMENTS

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In Volume V (pages 292 et seq.) of the *Philosophische Studien* Dr. Kirschmann describes a simple apparatus for the measurement of the light intensities of black, grey, and white papers in terms of one another. This apparatus has been improved and used in the Psychological Laboratory of the University of Toronto for measuring the intensities of the Prang and Milton-Bradley papers and other uncoloured pigments. While the main part of the apparatus, the disc with its movable sectors and the dark space, remained essentially the same, appropriate arrangements for securing constancy of illumination were added and the following is the description of the apparatus as now used. A large disc, made of stiff cardboard or aluminium and covered with Milton-Bradley's best white paper, is divided into quadrants, and from two opposite quadrants, about one inch from the outer edge, sections are cut out one inch in width, and 90° in length, and a graduated scale is made on the remaining quadrants. A smaller disc of the paper, of which the intensity is to be compared with that of the white is made so that the edge of this smaller disc reaches just beyond the inner edge of the open section. From a third disc two opposite sections of 120° each are removed so that the outer edges of this sector reach the inner side of the graduated scale, while the inner edges of the sector leave exposed two sections of the grey paper to be measured, each section 120° by one inch in width. A fourth disc with two opposite sections of 90° each removed forms a similar sector but with diameter equal to that of the first disc, and may be used as a "vernier" for the observations made with the preceding or smaller sector. When these are placed on a motor in the order named, and then revolved with sufficient speed to secure the complete validity of Talbot's Law [1] it is evident they will make two grey rings of different intensities surrounded by a white ground, but the outer ring will be influenced by what is behind the open section of the large disc. To get the lowest possible intensity in combination with the outer ring a box in

[1] See Articles of Professor Marbe on Talbot's Law.

the form of a truncated pyramid is lined with black velvet, the angular relation of the sides of the box to each other being such that no reflection is given through the small opening when the box is placed immediately behind the open section of the large disc. To avoid the effect of a changing illumination as in daylight, the experiments are made in a dark room with light only from four (or two) Auer lamps placed immediately over the revolving discs, and the illumination from the lamps, whose flames are in the focal line of a parabolically curved mirror, is reflected upon the disc by another and plane mirror in front, attached to a wooden screen behind which the observer sits and compares the intensities of the two grey rings on the white ground. It is quite evident that the intensities of the two papers can be compared at different positions of the sectors; thus a number of observations can be made with different combinations of the papers to be measured, as when the larger sector is placed at 10°, 15°, 20°, 25°, etc. When the larger sector is placed, say, at 40° and the angular widths of the opening and the grey to be measured are equal, it is evident that the outer ring will be considerably darker than the inner ring because the absolute black of the opening is, of course, much darker than the grey paper. By moving the smaller sector to the left, grey is added to the inner ring, i.e., more of the grey paper is exposed until a point is reached where the intensities of the two rings are estimated as equal. As a criterion for this condition we may use the complete blending into one ring without any separating line. From the point where the intensities are judged to be equal more grey may be added, without any noticeable difference until the point is reached where noticeable change begins. The average of the two judgments may be taken as the best procurable with the use simply of the smaller sector. But the changes produced by the smaller sector are comparatively large. For if the outer ring be 40° and the inner one 42°, and one degree be added to the latter, the relation of the two rings is changed from $\frac{42}{2}$ to $\frac{43}{2}$, that is, a difference of $\frac{1}{42.43}$ or 2.215%. Now the use of the larger sector makes possible a finer variation. If

in the above case the larger sector be moved for one degree the same angular amount is added (or taken away) from both rings. Consequently the change is from 40 and 42 to 41 and 43, i.e., the relation is changed from $\frac{40}{42}$ to $\frac{41}{43}$, that is, a difference of $\frac{1}{903}$ or 0.111%. Thus the larger sector, though without a graduated scale, serves as a kind of "vernier." The larger sector is used in the following manner. The limit of the adjustment for the smaller sector is half a degree. Thus, after ascertaining that position of the smaller sector where the two rings best blended, there would be found the limits for the position of the larger sector for which this blending was not destroyed. The average of the numbers indicating the limits would be taken into account in calculating the results.[1]

Let the angular opening of the disc into the velvet-lined box be a°. Then the components of the outer ring of grey are (360—a)° of white and a° of absolute black. Let the intensity of the absolute black be 0, and that of one degree of white be represented by x. The intensity of the outer ring, then, is $(360-a)x + a \times 0$.

Let the number of degrees of grey paper be represented by b, and let the intensity of one degree of the grey compared with white be 1. Then the components of the inner ring are (360—b)° of white and b° of grey. The intensity of the inner ring is $(360-b)\,x + b \times 1$.

When the two rings are judged as equal there is the following equation:—[2]

$$(360-a)x + a \times 0 = (360-b)x + b \times 1$$

$$360x - ax = 360x - bx + b$$

$$bx - ax = b$$

$$x = \frac{b}{b-a}$$

Since 1900, Professor Kirschmann has given the writer charge of the photometrical measurements required for various purposes and the following tables contain a few results which

[1] The accompanying cut (Plate C) from a stereoscopic photograph may be of some assistance in understanding the apparatus.

[2] *Philos. Studien*, V, 297.

might be of interest generally and in connection with other articles in this number. Table I contains results of experiments made in ordinary daylight by three observers, Messrs. Coleman, Farrell and Smith. The number in the column headed "relation to white" indicates how many times as bright Milton-Bradley's white was as the grey or black paper named in the first column. In the second column, headed "Average," all the numbers refer to black as one. They indicate how many times as bright was the grey or white in question as the Milton-Bradley black which is taken as unity.

Table II contains the results of experiments made in 1901-2 by Messrs Van Wyck and Archer, and in 1902-3 by Messrs. Ross and Graham.

In all these results of Table II artificial light (Auer light) was used, in those of Table I ordinary daylight. After the explanation given for Table I, Table II is easily understood. The results of Table II are different from those of Table I because of the different conditions of illumination. Also the lead pencil and China ink were not the same for the different groups.

Finally, it may be mentioned that the coincidence of the average to the second decimal of the four series of Van Wyck and the four of Archer is purely accidental, but a still greater freak of accident is the curious fact that when Messrs. Ross and Graham made the experiments with the same paper the averages of the results of six series of each again coincided to the third decimal.

TABLE I.—ILLUMINATION BY DAYLIGHT.

NAME OF PAPER OR PIGMENT	SMITH		COLEMAN		FARRELL		TOTAL (AVERAGE)		TOTAL (AVERAGE)
	Num. of Trials	Ratio to White	Num. of Trials	Ratio to White	Num. of Trials	Ratio to White	Num. of Trials	Ratio to White	Referring to M Bradley's Black as 1
Milton Bradley's Black	3	44.542	6	42.997	2	40.83	11	43.074	
" Neutral Grey I	2	2.638	2	2.616	3	2.567	7	2.601	16.561
" Neutral Grey II	4	3.625	3	3.688	4	4.025	11	3.782	11.380
" Warm Grey I	"	"	3	2.675	"	"	3	2.675	16.148
" Warm Grey II	"	"	5	5.130	5	5.410	10	5.270	8.156
" Cool Grey I	"	"	4	2.212	3	2.061	7	2.147	20.062
" Cool Grey II	"	"	5	3.655	4	3.798	9	3.718	11.585
" White	"	"	"	"	"	"	"	"	43.074
Prang's Lighter Grey	"	"	3	2.499	4	2.597	7	2.504	17.202
" Light Grey	"	"	3	4.515	4	4.216	7	4.344	9.916
" Grey	"	"	3	6.564	4	6.597	7	6.583	6.467
" Dark Grey	"	"	7	8.773	4	8.661	11	8.737	4.933
" Darker Grey	"	"	6	10.208	4	9.959	10	10.101	4.261
Black Card-Board	3	25.682	"	"	"	"	3	25.682	1.697
Lead Pencil (Faber B1)	2	13.475	3	11.435	6	15.688	11	13.031	3.305
China Ink	5	15.458	3	16.097	4	17.058	12	16.151	1.097

TABLE II.—ILLUMINATION BY AUER-LIGHT

NAME OF PAPER OR PIGMENT	ARCHER		VAN WYCK		GRAHAM		ROSS		TOTAL (AVERAGE)		TOTAL (AVERAGE)
	No. of Trials	Ratio to White	No. of Trials	Ratio to White	No. of Trials	Ratio to White	No. of Trials	Ratio to White	No. of Trials	Ratio to White	Referring to M. Bradley's Black as 1
Milton Bradley's Black			8	40·620					8	40·620	1
" " Neutral Grey I	3	2·030	4	3·015	6	3·365	6	3·321	19	3·209	12·658
" " Neutral Grey II	6	5·138	5	5·503	6	4·107	6	4·302	23	4·754	8·544
" " Warm Grey I	4	3·175	4	3·710	6	3·044	6	3·586	20	3·546	11·455
" " Warm Grey II	4	7·110	4	7·110	6	5·147	6	5·147	20	5·933	6·846
" " Cool Grey I	4	2·622	4	2·600	6	3·286	6	3·505	20	3·082	13·180
" " Cool Grey II	4	7·610	4	7·750	6	4·654	6	4·803	20	5·925	6·856
" " White											40·620
Prang's Lighter Grey	3	2·444	4	2·900	6	3·754	6	3·837	19	3·413	11·902
" Light Grey	4	5·086	4	5·061	6	4·778	6	5·117	20	5·004	8·116
" Grey	4	8·873	8	9·286	6	8·303	6	7·953	24	8·501	4·728
" Dark Grey					6	11·483	6	11·682	12	11·583	3·507
" Darker Grey			10	15·018	6	15·330	6	14·483	22	15·250	2·667
Black Card-Board	3	31·68	4	33·450					7	32·690	1·243
Lead Pencil (Faber BB)	3	14·82	4	10·900					7	12·614	3·220
China Ink			3	22·500					7	22·500	1·804
Printers' Ink					4	22·044	4	21·584	8	22·114	1·837
Printers' Ink (Thicker)					4	24·434	4	24·392	8	24·413	1·664

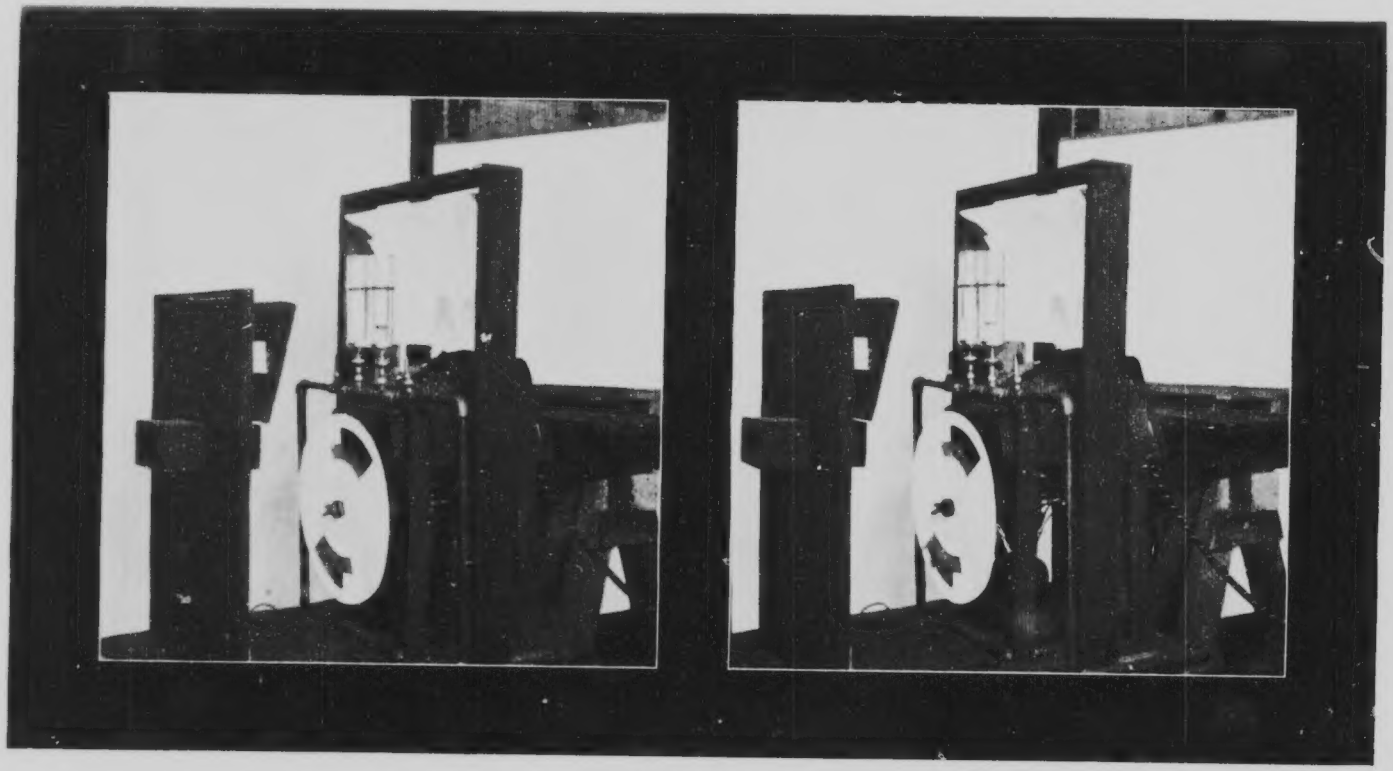

PLATE C.